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ACIDIC DEPOSITION PRODUCTION MECHANISM

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INTRODUCTION

A consequence of the launch of STS-1 on April 12, 1981, was a light deposition of acidic material observed on foliage and pH papers at sites as far as 7.4 km from the launch pad. To explain the origin of this fallout, a study was undertaken consisting of the following data: field measurements during the launches of STS-2 through STS-4; cloud measurements by a hurricane research aircraft[a] equipped with special cloud microphysics instrumentation; fallout studies of 6.4-percent Shuttle model firings at Marshall Space Flight Center (MSFC); and scientific and numerical analyses. In this paper, results are documented that relate to the primary objective of the study: the production mechanism of the acidic deposition.

Numerous individuals, organizations within the U.S. Government, and support contractors contributed to this study. Of special assistance were the following: NOAA Research Facilities Center; NOAA National Hurricane Research Laboratory; State University of New York at Albany; Universities Space Research Association; U.S. Air Force Space Command, Los Angeles, California; Biomedical Office and Environmental Management Staff, John F. Kennedy Space Center (KSC); Space Environment Office, Lyndon B. Johnson Space Center (JSC); and the MSFC Test Laboratory.

The primary characteristics of the acidic deposition are as follows:

1. Deposition occurs with every launch. Acidic deposition was observed after STS-1, STS-2, STS-3, STS-4, and STS-5 and in 6.4 percent of the model tests of the Western Test Range (WTR) configuration.

2. The pH is less than 0.5. Samples collected at pad perimeter measure 0.5 (STS-2) and 0.36 (STS-4). The pH paper on aircraft foil impactor confirms pH approximately 0.5 (STS-3).

3. Deposition is composed of water (large fraction), Al_2O_3 particles, and HCl. A sample collected at the pad indicates 70 percent liquid and 30 percent solids. Micrographic analysis of deposits on copper plates supports this estimate.

4. Deposition forms very rapidly. Millimeter-sized drops were present in the cloud at the first aircraft penetration, L + 4 minutes. Because of the pattern of deposition near the pad, one infers formation time less than 60 sec.

5. The deposition outside the pad perimeter has drop diameters up to 2,000 μm. Figures 1, 2, and 3 illustrate size distributions measured by airborne instruments and the copper plate method. Particles smaller than 100 μm have usually dried before reaching the ground.

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[a]National Oceanic and Atmospheric Administration (NOAA) WP-3 at the Research Facilities Center, Miami, Florida, provided the cloud measurements.

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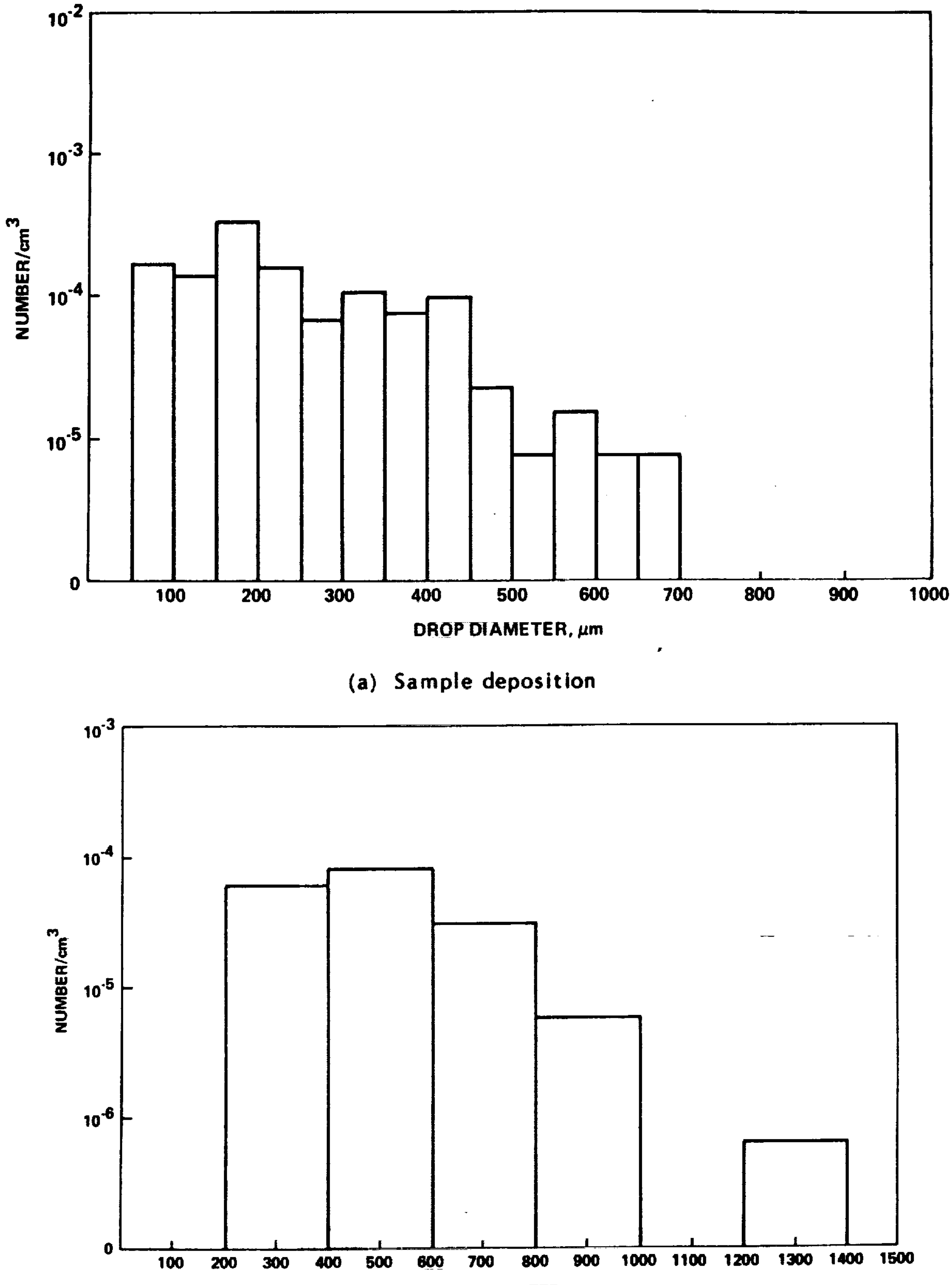
DISCUSSION

These observations lead to the conclusion that the deposition is formed by atomization of the deluge water at the launch pad. This results from mechanical interaction of the exhaust jet with the water. The atomization produces water drops which very rapidly (within a few seconds) scavenge sufficient HCl and Al_2O_3, explaining the observed pH and solid fraction. Measured updrafts in the cloud exceed 4 m/s. This is sufficient to lift the millimeter-sized deposition drops with the cloud to levels where they are carried downwind and deposited in both the near- and far-field.

Other possible formation processes were considered, but they are incapable of explaining the observations. Upper limit rate computations of formation by condensation or condensation-coalescence processes indicate that these processes are too slow to account for the rapid production rate. Most conclusively, these processes cannot account for 6.4-percent model tests where the very small clouds last for only 2 to 3 min. Direct production by the vehicle is ruled out by the high liquid fraction observed, among other reasons. However, these processes are, or at least can be, occurring and influencing the observations in a subsidiary way. Certainly, scavenging (coalescence) is the mechanism for the incorporation of Al_2O_3 into the deposition. It is a sufficiently rapid process when the collector drop begins at a large size. Also, there is some tenuous evidence for the production of a few large particles in the column cloud - either by coalescence or direct production from the vehicle, perhaps by erosion of the solid-rocket booster (SRB) nozzles.

CONCLUSION

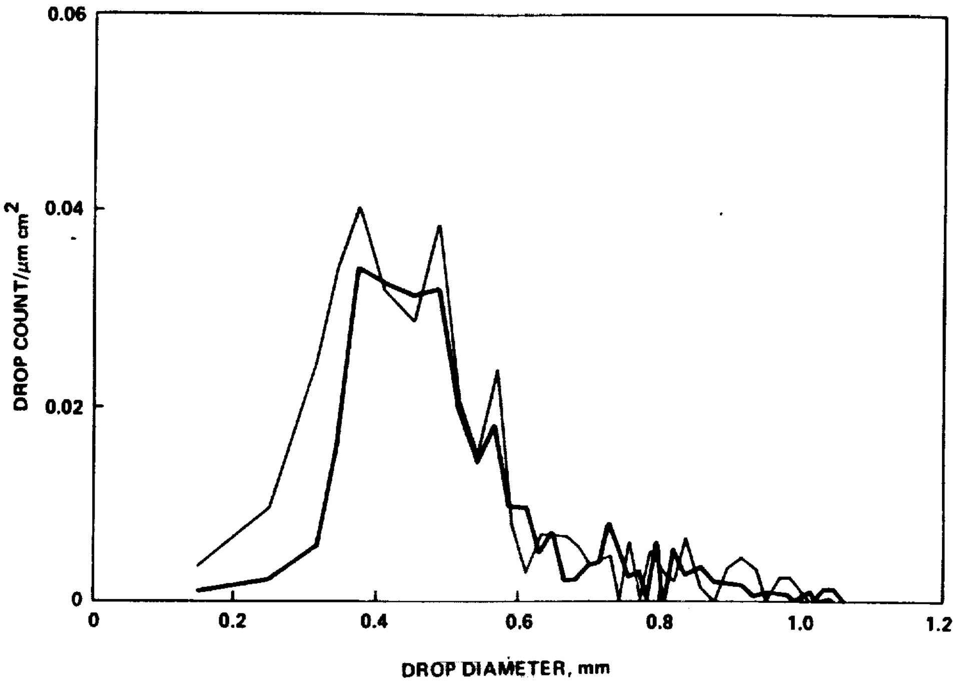
One may conclude from this study that the acidic deposition will continue to occur with each Shuttle launch. Given a fixed vehicle, a pad, and deluge water configuration, the quantity produced in normal, fair-weather meteorological conditions will remain relatively constant. The location at which it is deposited will vary with the low-level wind conditions and atmospheric stability at launch time.



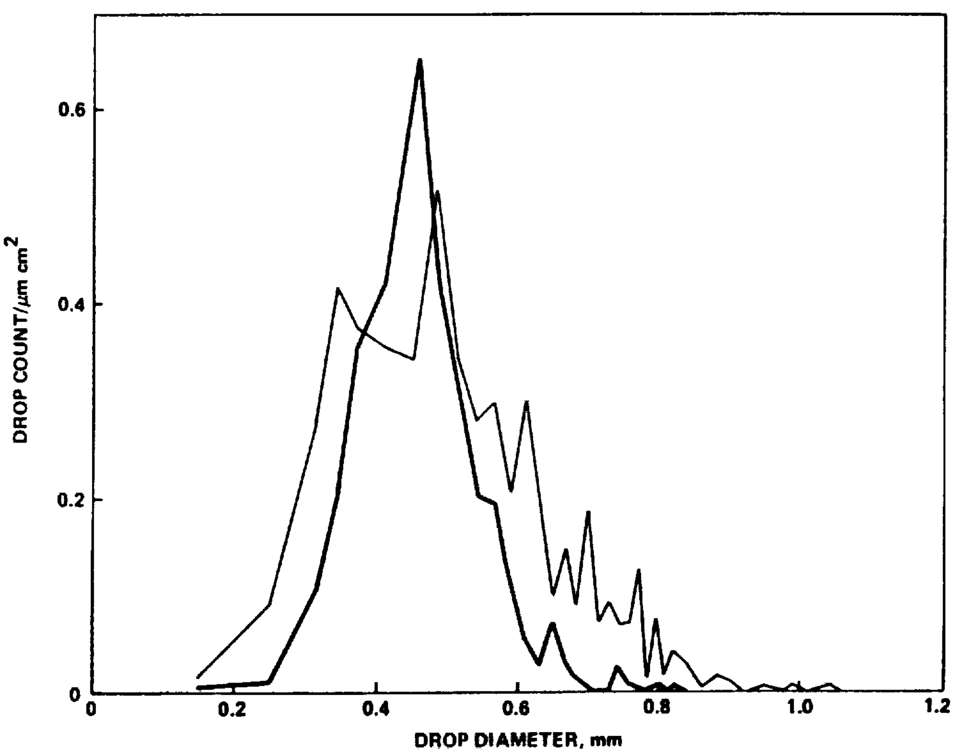
(a) Sample deposition

(b) Another sample deposition

Figure 1.- Size distributions measured by airborne instruments.

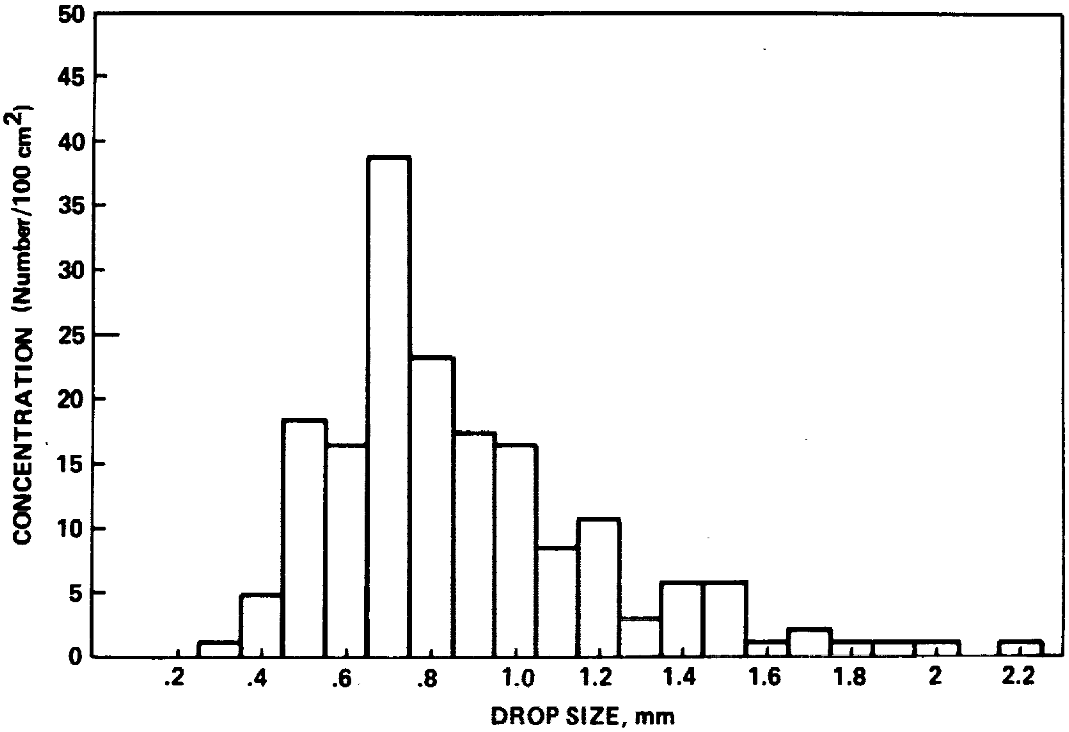


(a) Plate 17

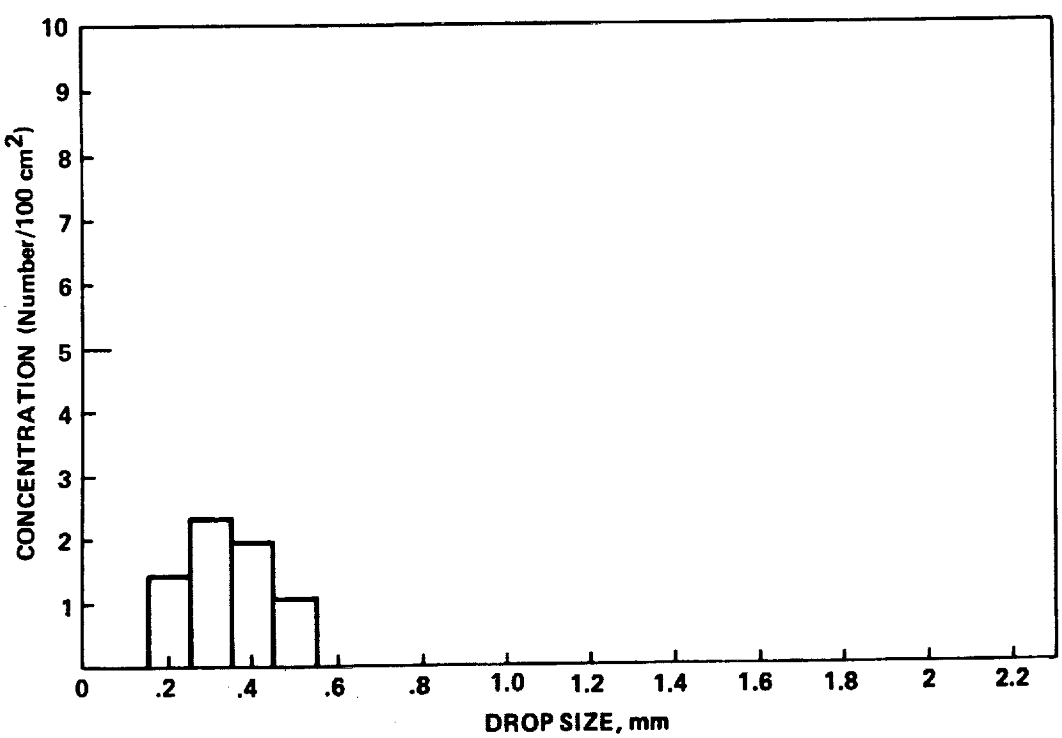


(b) Plate 15

Figure 2.- Drop count and drop diameter measured by copper plate method.



(a) Plate 44



(b) Plate 50

Figure 3.- Size distribution measured by the copper plate method.

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